

Yale 耶鲁大学-南京信息工程大学大气环境中心



Yale-NUIST Center on Atmospheric Environment

REMOTE SENSING WITH DRONES

YNCenter Video Conference

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08-28-2015

Drone remote sensing

- It was first utilized in military context and has been given great attention in civil use in recent years.
- Three Unmanned Aerial Systems (UAS) components:

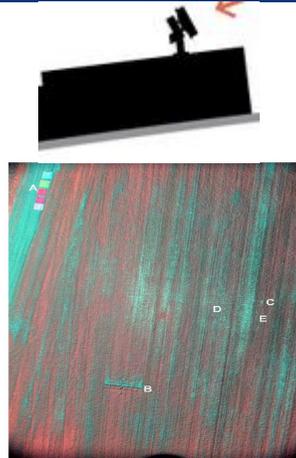
Source: Colomina et al. (2014)

Unmanned Aerial Vehicle



Source: Jaime et al. (2014)

Ground Control Station



Source: Hunt et al. (2010)

Communication data link



- **UAS classification**
- aerial platform (size and weight, endurance, aerodynamics, etc.);
- the system operation (mission range or flying altitude, nature of its application, etc.)
- **Cameras**
- RGB; multi-spectral; hyperspectral and thermal-imaging camera

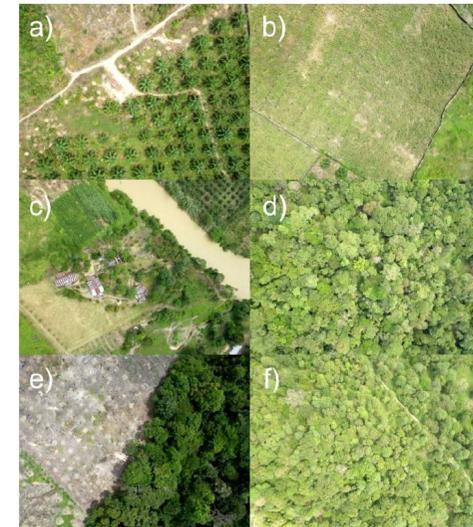
Common and/or representative multispectral cameras for UAS.

Manufacturer and model	Resolution (Mpx)	Size (mm ²)	Pixel size (μm)	Weight (kg)	Spectral range (nm)
Tertracam	CMOS	6.66	5.2	0.7	450–1050
MiniMCA-6	1.3	×5.32	×5.2		
Quest Innovations	CCD	10.2	7.5	0.8	400–1000
Condor-5 UAV-285	1.4	×8.3	×8.1		

Source: Colomina et al. (2014)

Pros and cons of UAV

- **Pros:**
 - High spatial and temporal resolution
 - Manually controlled (altitude, route...) not labor-intensive
 - Rarely affected by cloud cover
 - Cost-effective
 - Flexibility
- **Cons:**
 - Sensitive to wind
 - Poor geometric and radiometric performance
 - Short flight endurance

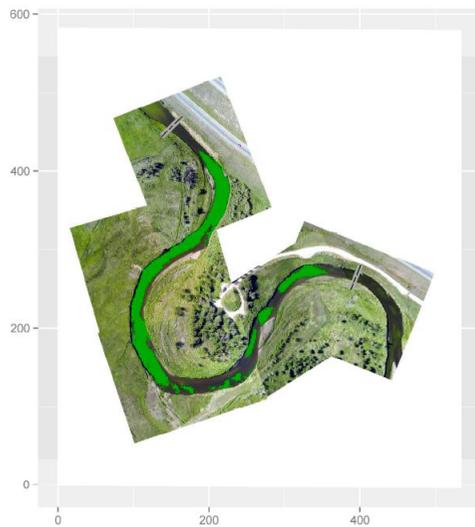


Source: Lian et al. (2012)

Source: Colomina et al. (2014)
Jaime et al. (2014)

Application of UAVs

- High resolution of digital elevation model
- Precision agriculture
- Water plant monitoring
- Forest inventory (gap vs biodiversity)
- Atmospheric science (aerosol)



Source: Flynn et al. (2014)



Source: Lian et al. (2012)



Source: Getzin et al. (2012)

Objectives

- Exploring the image processing and analyzing techniques based on the data we have.
- Finding new points.

Data introduction

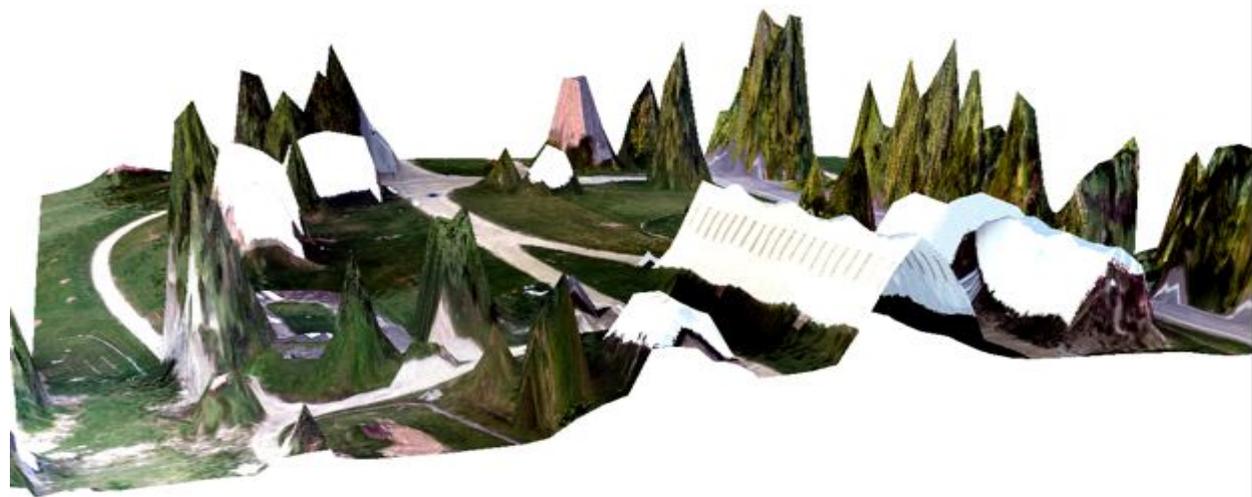
Name	Location	Time	Band	Point Cloud
Goshen	CT, US	Mar, 2014	R, G, B	Yes
Goshen_Nov_RGB	CT, US	Nov,2014	R, G, B	Yes
Goshen_Nov_NIR	CT, US	Nov, 2014	G,R, NIR	Yes
Cheshire	CT, US	Apr, 2015	G, R, Red edge, NIR	No
Maryland State Park	MD, US	Mar, 2015	No	Yes

Goshen



Figure 1 | Goshen image

3D map in ENVI

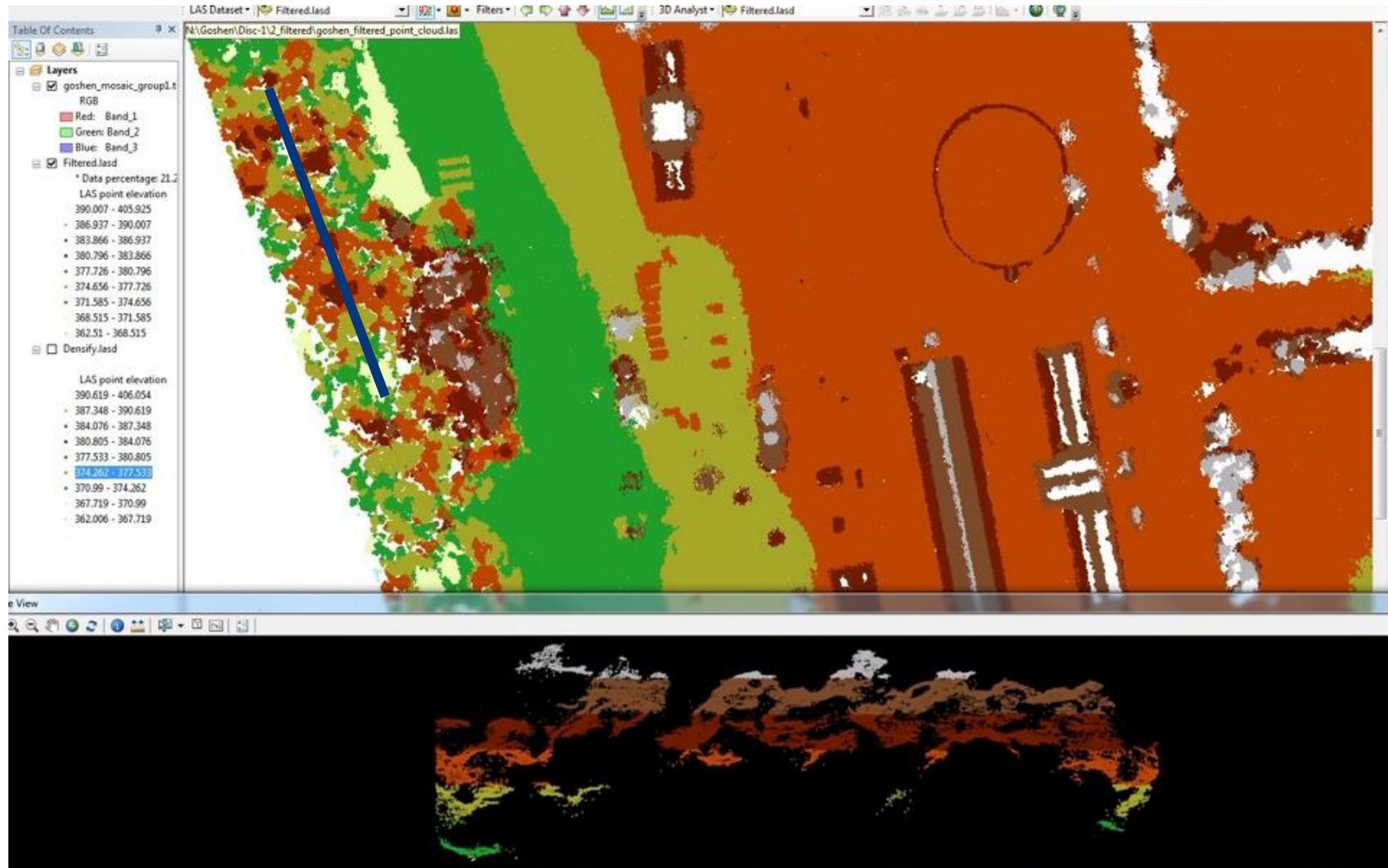


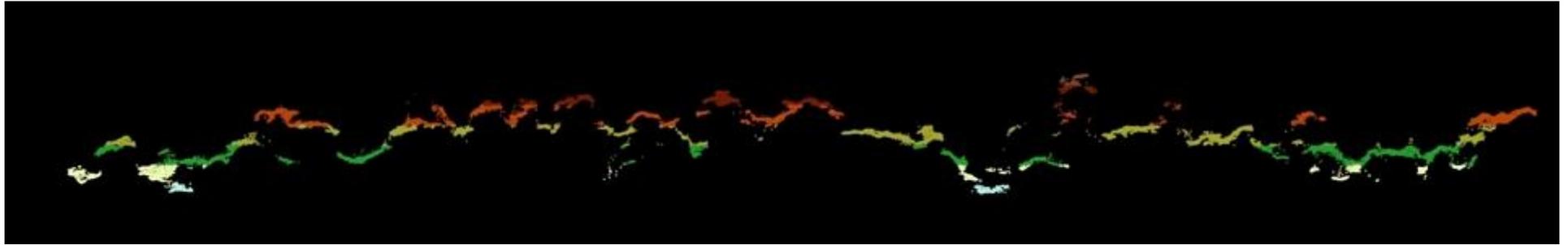
3D map in ArcGis



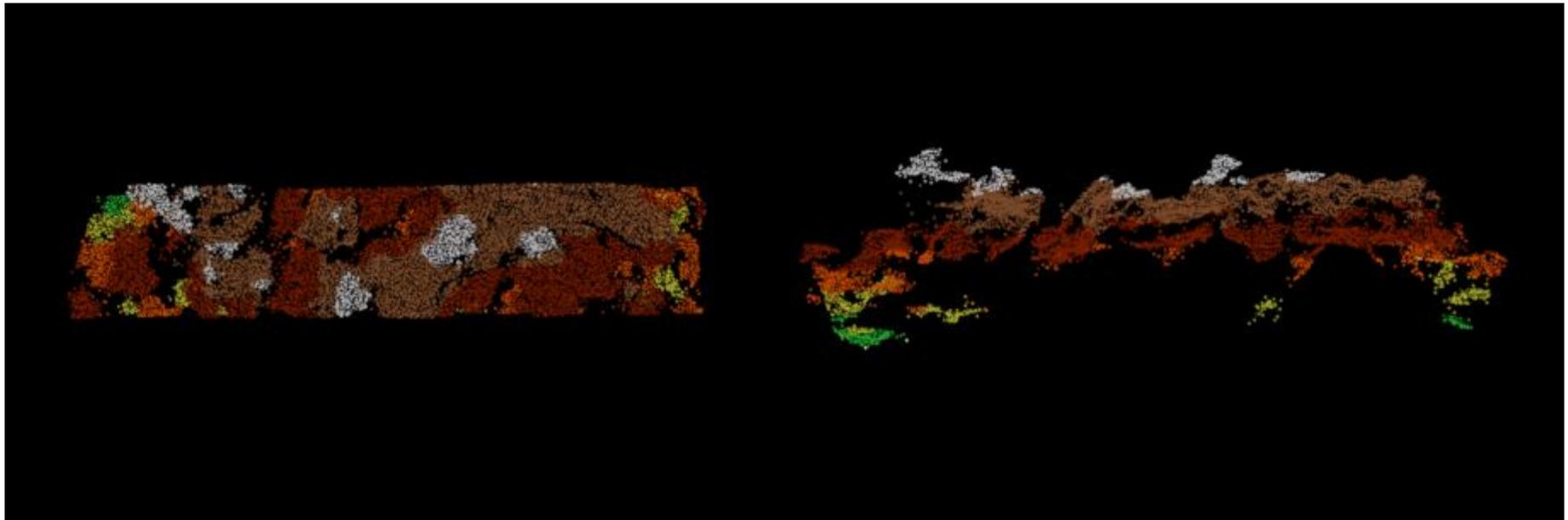
The boundaries of road and trees are not clear.

Point Cloud Visualization in ArcGIS





X-Z Plane



X-Y Plane

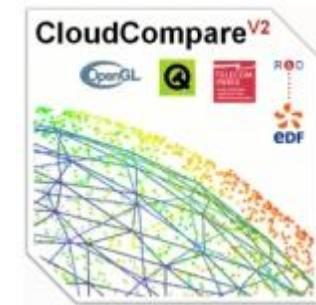
X-Z Plane

Goshen November

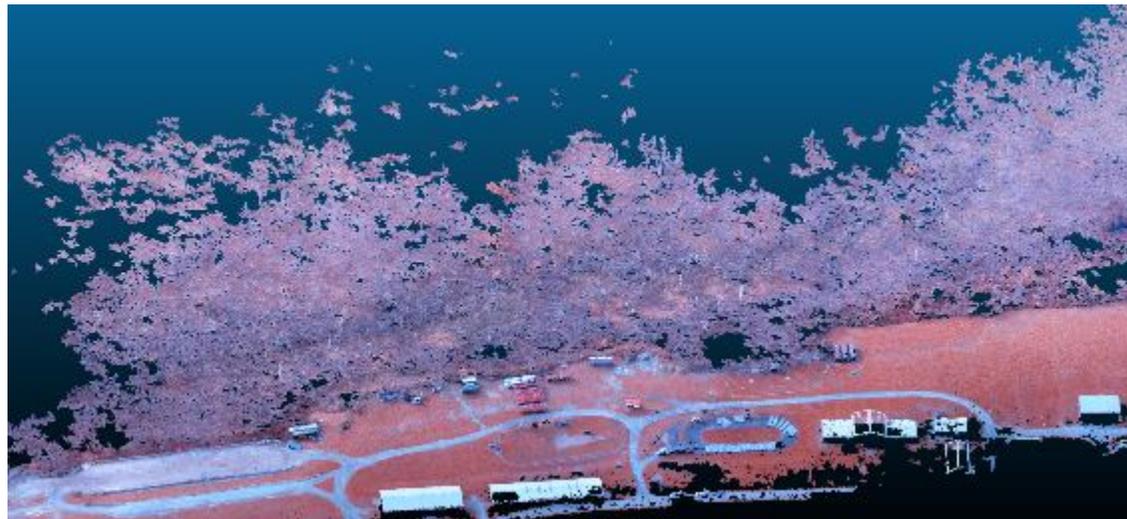


Figure 2 | Goshen images taken in Nov, 2014

3D view of Goshen images in CloudCompare



3D view of Goshen images (NIR)



Point cloud – remove things

Original image

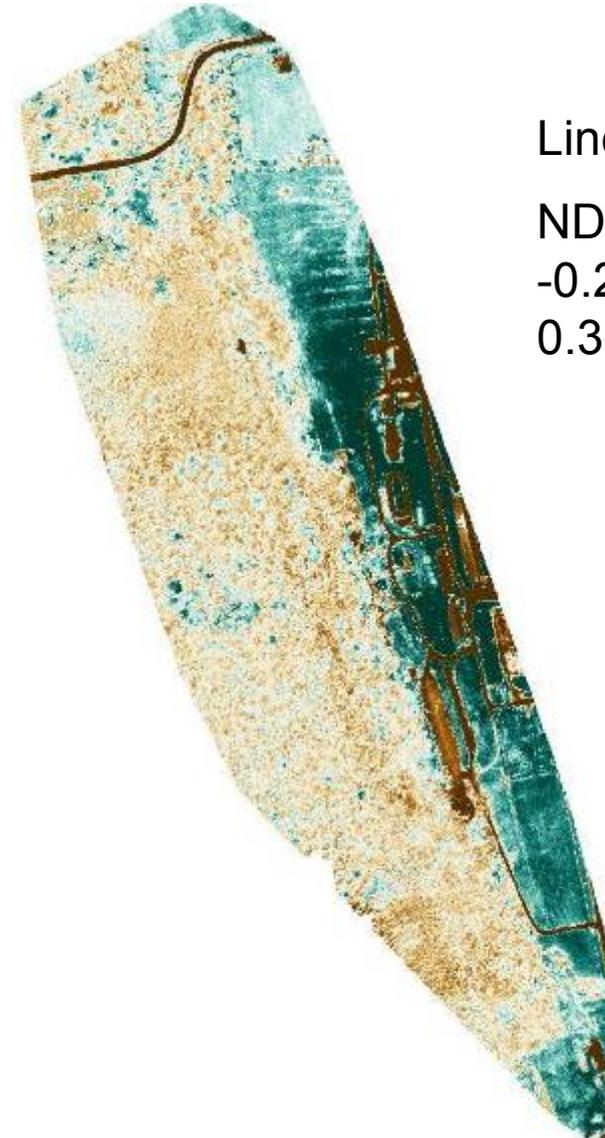
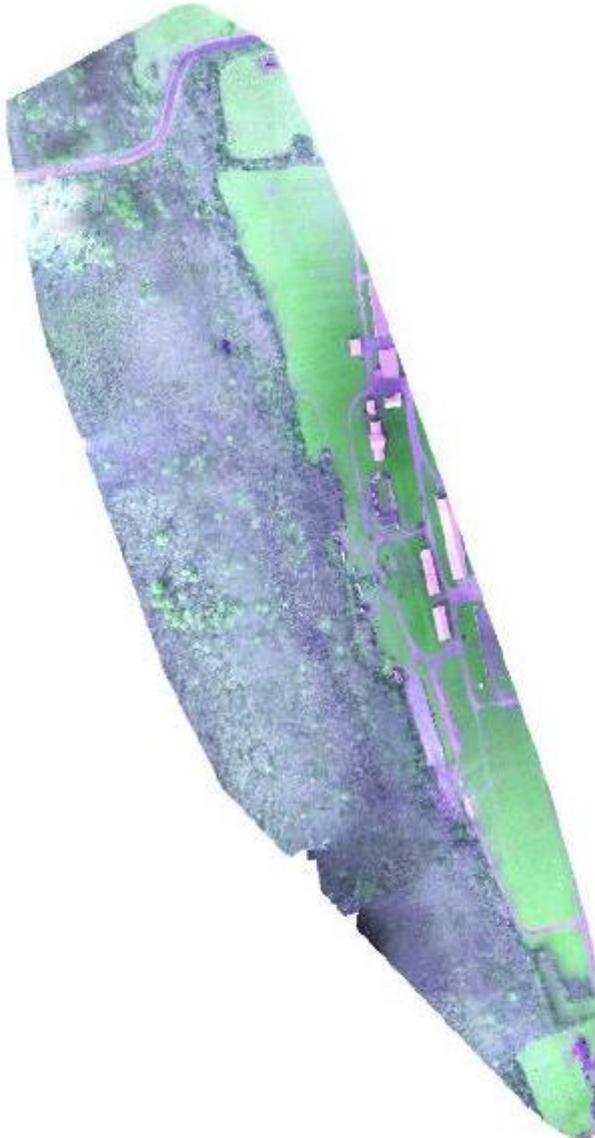


Translated image



NDVI Goshen November

- Red
- NIR
- Green



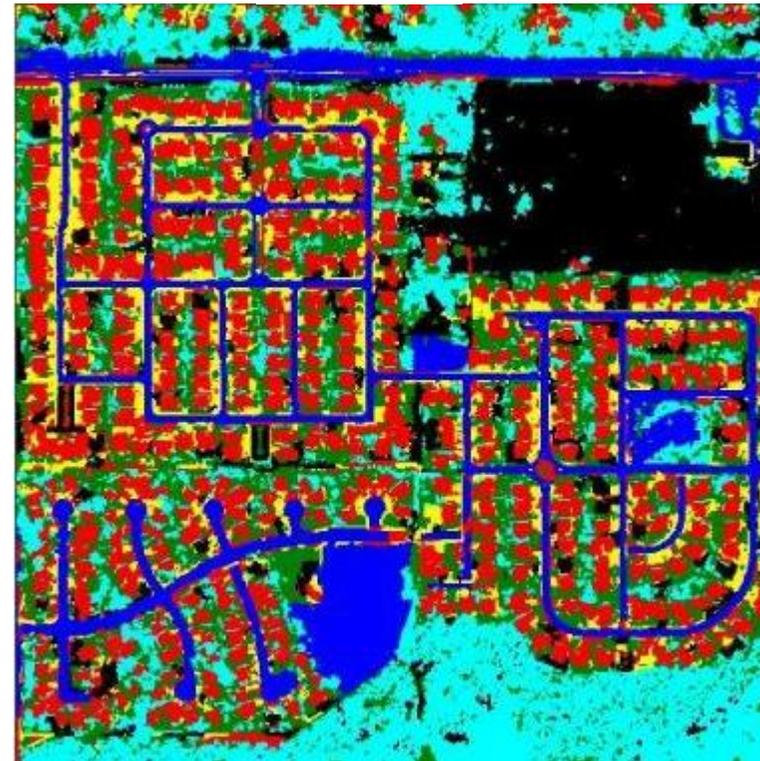
Linear 5%
NDVI range:
-0.2269
0.3561

Feature extraction module in ENVI

- RED (0.6600)
- GREEN (0.5600)
- BLUE (0.4850)



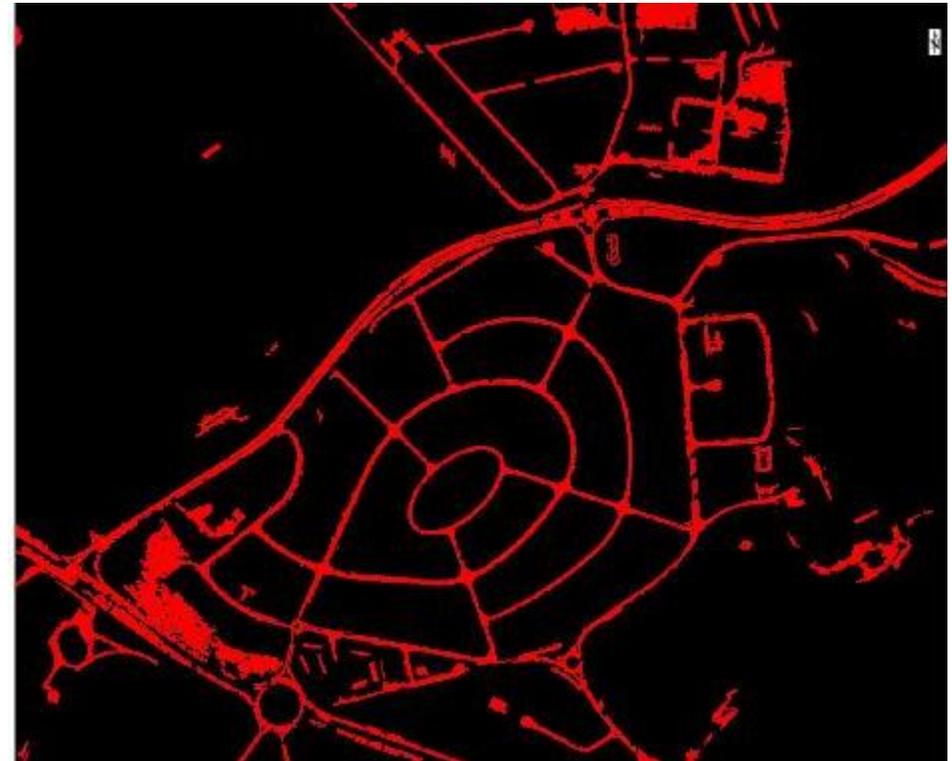
- 0: Unclassified
- 1: Rooftop
- 2: Grass
- 3: Asphalt
- 4: Concrete
- 5: Trees
- 6: Masked



Example-based Classification

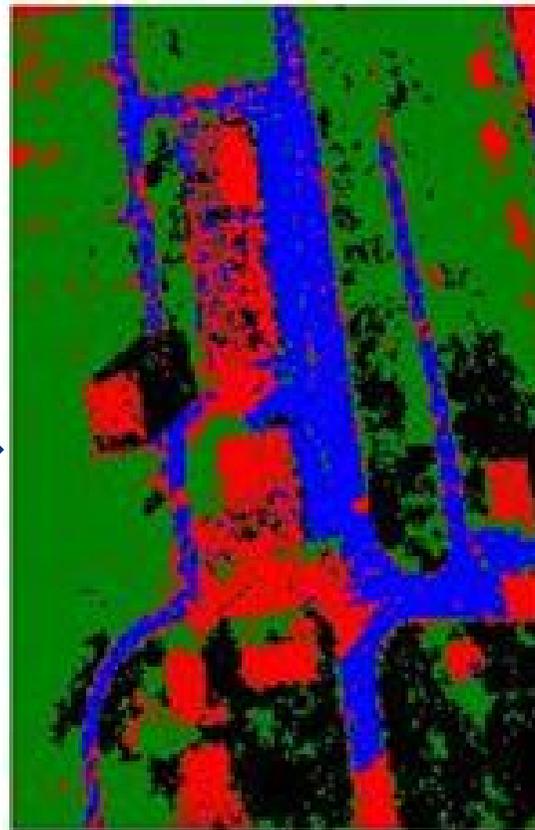
- Band 3 (0.6725)
- Band 2 (0.5450)
- Band 1 (0.4800)

- 0: Unclassified
- 1: Asphalt
- 2: Masked



Rule-based Classification

Goshen- Extract roof (red)



Feature extraction on Goshen NIR image

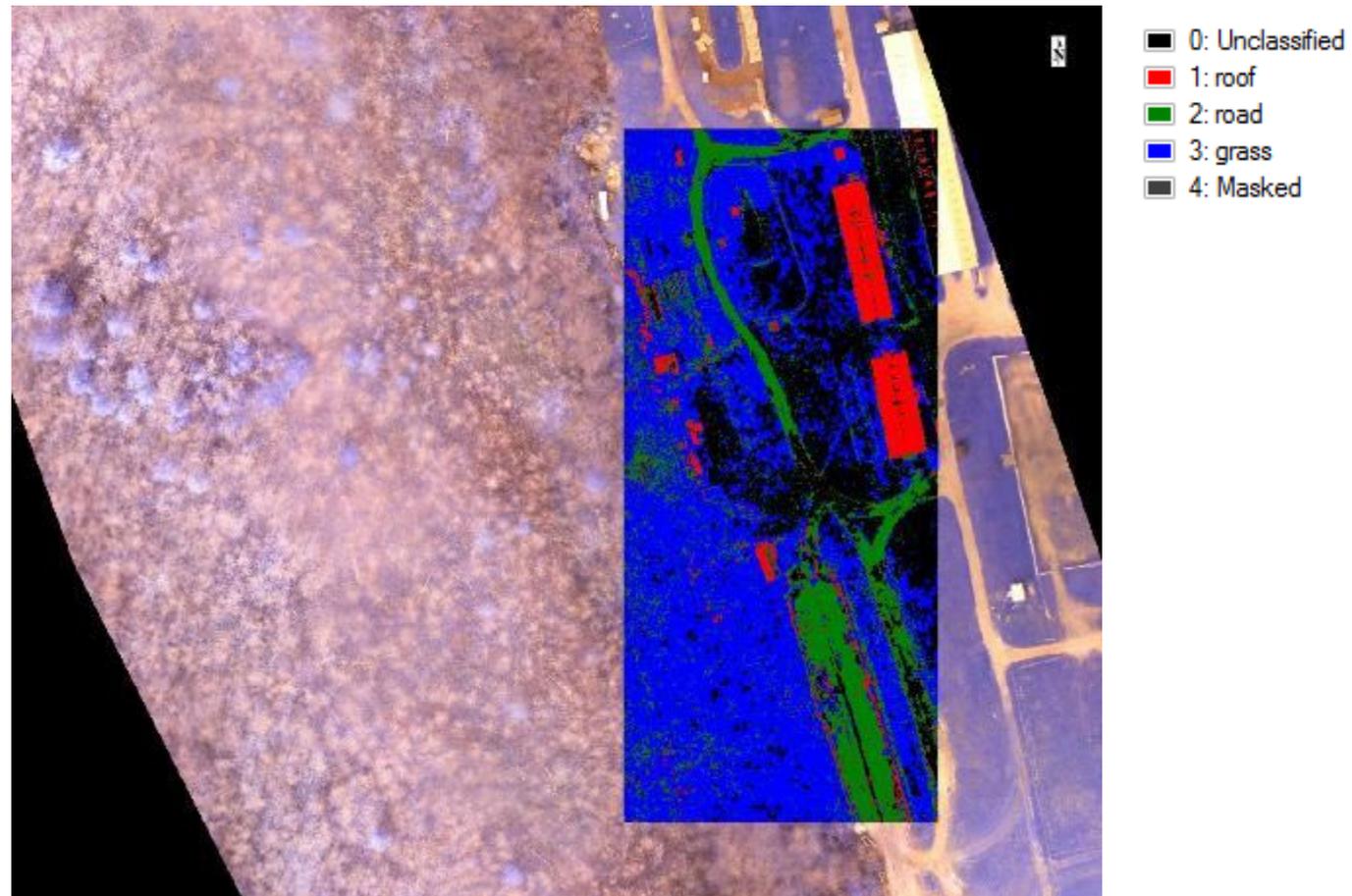


Figure 3 | Example-based classification of roof

Rule-based feature extraction vegetation

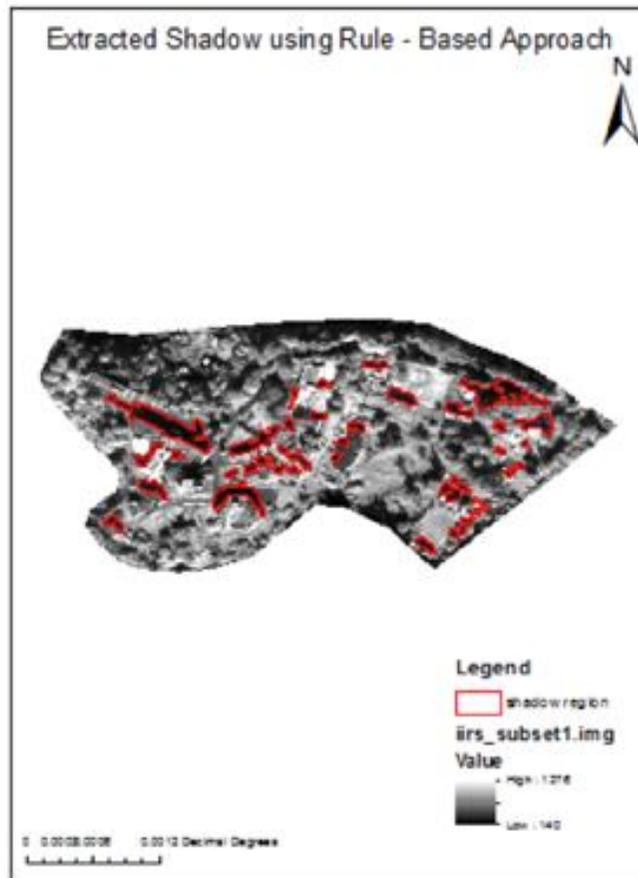


Rule:

spectral mean of band 1 (red): 57 to 160

spectral mean of band 2 (green): 57 to 149

Extract shadow



Source: Raju et al, (2014)



Figure 4 | Rule-based classification of shadow for Goshen data (yellow represents shadow)



Suppose building 1's height is unknown and that of building 2 is known (suppose it is 10m).

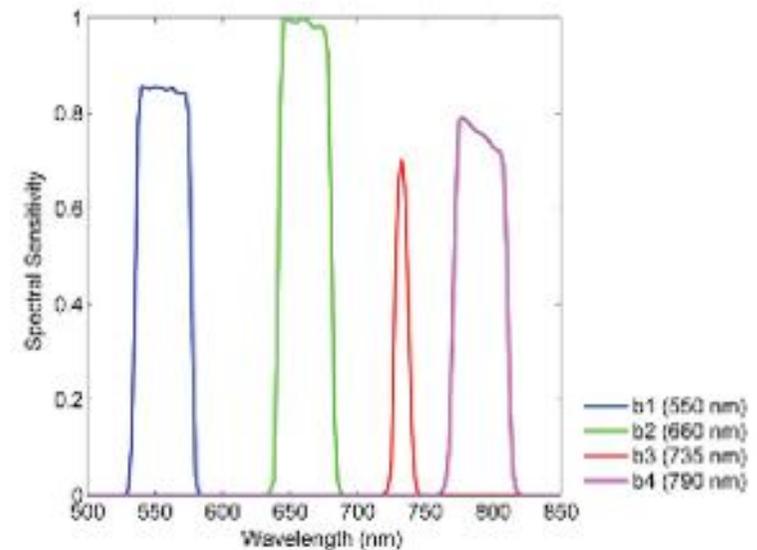
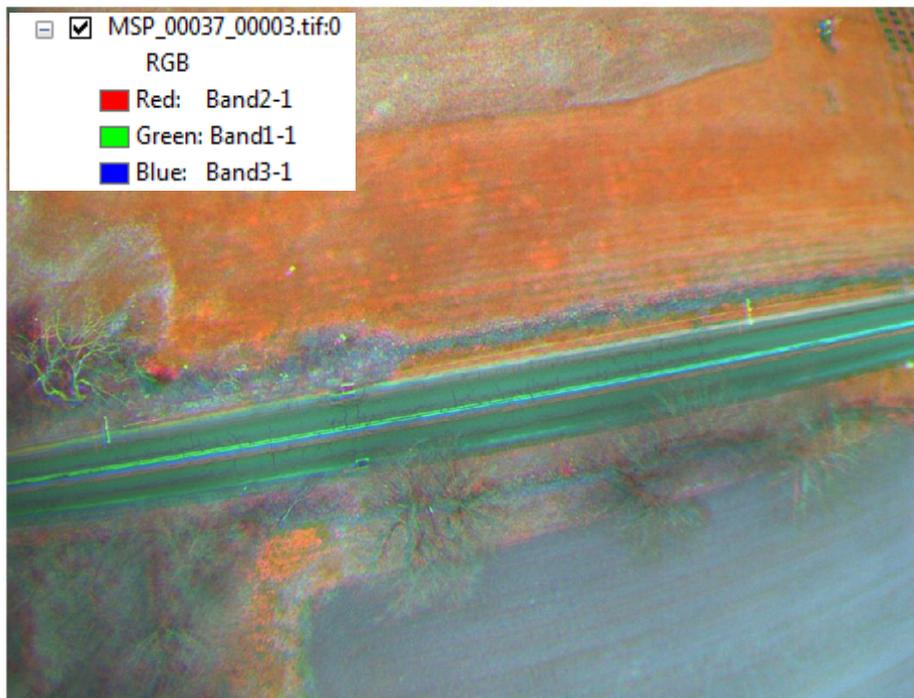
Using measuring tool in ENVI:

$Sl_{un} = 20.56\text{m}$, $sl = 14.04\text{m}$

$H_{un} = (20.5648 * 10) / 14.0357 = 14.65\text{m}$

Cheshire image processing in Pix4D

- Camera: multiSPEC4C_3.6_1280*960
- (**Exiftool**)
- Green, Red, Red Edge, NIR (4 bands)



Flight path (Pix4D)



Figure 5 | Flight path of Cheshire in Google map

Cheshire

Image bands separation (**gdal_translate**)

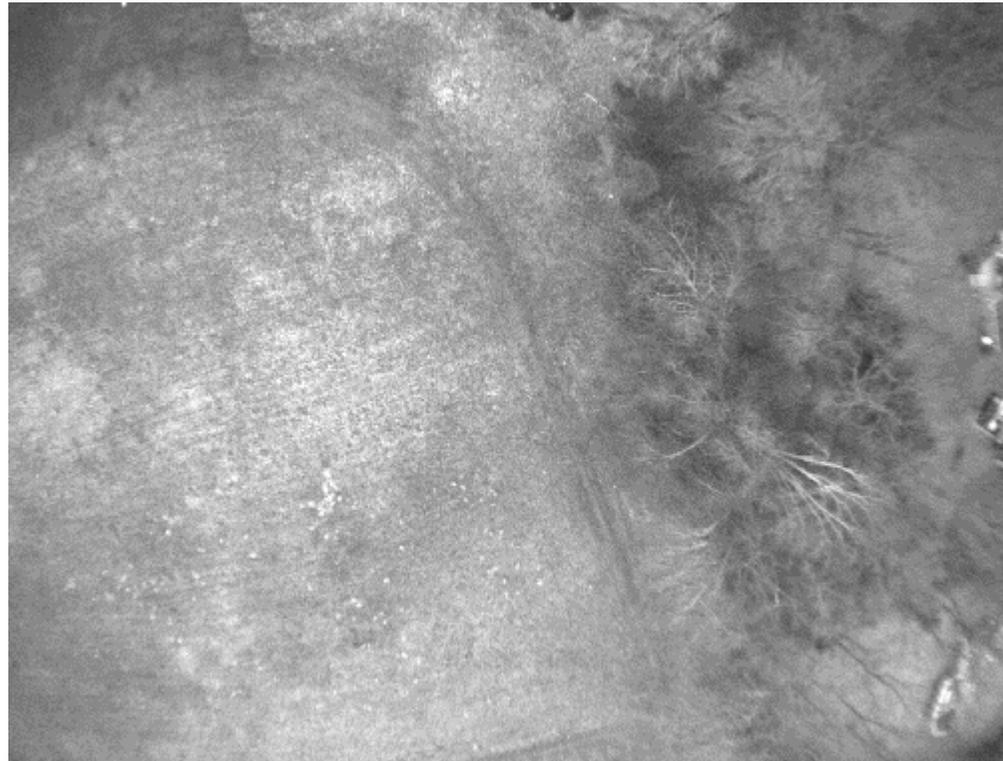


Figure 6 | Merged image of Cheshire red band

OpenDroneMap

- Install virtual machine (GitHub) and enter Linux command
- Input: UAV raw images (with geographic information)
- Output: point cloud; meshing data
- Example: Goshen November RGB Images (6 images)

```

0 0 0 0
Expanding patches...
---- EXPANSION: 1 secs ----
Total pass fail0 fail1 refinepatch: 1578 801 375 402 1203
Total pass fail0 fail1 refinepatch: 100 50.7605 23.7643 25.4753 76.2357
FilterOutside
mainbody:
Gain (ave/var): 1.36946 0.239593
29820 -> 29820 (100%) 0 secs
Filter Exact: xxxxxx
29820 -> 29773 (99.8424%) 0 secs
FilterNeighbor: 29773 -> 29655 (99.6037%) 0 secs
FilterGroups: 20
29655 -> 29609 (99.8449%) 0 secs
STATUS: 314 0 38953 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 0
---- Total: 0 secs ----

- running meshing - Thu Aug 6 22:15:43 UTC 2015

- running texturing - Thu Aug 6 22:16:16 UTC 2015

- running georeferencing - Thu Aug 6 22:26:48 UTC 2015
Warning: No GCP file. Consider rerunning with argument --odm_georeferencing-useg
cp false --start-with odm_georeferencingSkipping orthophoto
Compressing results - Thu Aug 6 22:26:48 UTC 2015

- done - Thu Aug 6 22:26:51 UTC 2015

```

```

using IMG_4663.jpg dimensions: 4272x2848 / focal: 28.0mm / ccd: 22.30mm
using IMG_4669.jpg dimensions: 4272x2848 / focal: 28.0mm / ccd: 22.30mm
using IMG_4672.jpg dimensions: 4272x2848 / focal: 28.0mm / ccd: 22.30mm
using IMG_4675.jpg dimensions: 4272x2848 / focal: 28.0mm / ccd: 22.30mm
using IMG_4678.jpg dimensions: 4272x2848 / focal: 28.0mm / ccd: 22.30mm
using IMG_4684.jpg dimensions: 4272x2848 / focal: 28.0mm / ccd: 22.30mm
using IMG_4696.jpg dimensions: 4272x2848 / focal: 28.0mm / ccd: 22.30mm
using IMG_4702.jpg dimensions: 4272x2848 / focal: 28.0mm / ccd: 22.30mm
using IMG_4708.jpg dimensions: 4272x2848 / focal: 28.0mm / ccd: 22.30mm
using IMG_4711.jpg dimensions: 4272x2848 / focal: 28.0mm / ccd: 22.30mm
using IMG_4714.jpg dimensions: 4272x2848 / focal: 28.0mm / ccd: 22.30mm

found 11 usable images
using max image size of 2400 x 2400
- preparing images - Thu Aug 6 22:01:44 UTC 2015

resizing IMG_4663.jpg to /vagrant_data/odm_data/pacifica/reconstructio
n-with-image-size-2400/IMG_4663.jpg (2400 x 1600)
resizing IMG_4669.jpg to /vagrant_data/odm_data/pacifica/reconstructio
n-with-image-size-2400/IMG_4669.jpg (2400 x 1600)
resizing IMG_4672.jpg to /vagrant_data/odm_data/pacifica/reconstructio
n-with-image-size-2400/IMG_4672.jpg (2400 x 1600)
resizing IMG_4675.jpg to /vagrant_data/odm_data/pacifica/reconstructio
n-with-image-size-2400/IMG_4675.jpg (2400 x 1600)
resizing IMG_4678.jpg to /vagrant_data/odm_data/pacifica/reconstructio
n-with-image-size-2400/IMG_4678.jpg (2400 x 1600)
resizing IMG_4684.jpg to /vagrant_data/odm_data/pacifica/reconstructio
n-with-image-size-2400/IMG_4684.jpg (2400 x 1600)
resizing IMG_4696.jpg to /vagrant_data/odm_data/pacifica/reconstructio
n-with-image-size-2400/IMG_4696.jpg (2400 x 1600)
resizing IMG_4702.jpg to /vagrant_data/odm_data/pacifica/reconstructio
n-with-image-size-2400/IMG_4702.jpg (2400 x 1600)

```

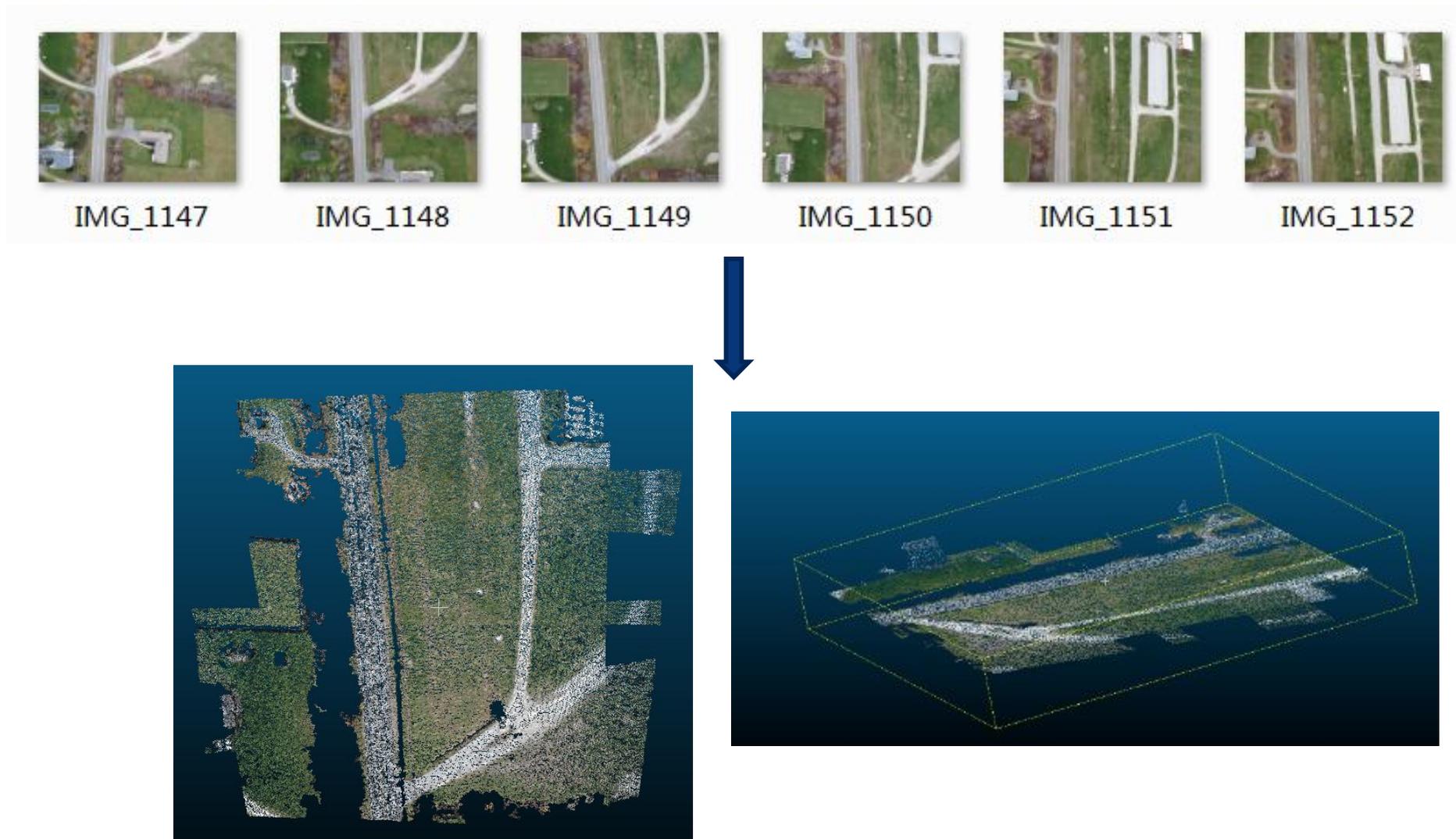


Figure 7 | Cloud point data generated from OpenDroneMap

Next work

- New index
- Image interpretation combined with field measurement
- New function exploration of UAV softwares

Table 1. Spectral indices used in the present study calculated using MCA sensor set of bands

Index	Equation	References
Chlorophyll absorption ratio	$CAR = \frac{[(R700 - R900) \times (R710 - R850) - (R750 - R900) \times (R700 - R710)]}{\sqrt{(R700 - R900) \times (R710 - R850)}}$	Broge and Leblanc (2001)
Chlorophyll absorption ratio	$CARI = CARI + \frac{R790}{R710}$	Kim et al. (1994); Broge and Leblanc (2001)
Greenness index	$GI = \frac{R50}{R70}$	Zarco-Tejada et al. (2005a, b)
Green normalized difference vegetation index	$GNDVI = \frac{R81 - R52}{R81 + R52}$	Gitelso and Merzlyak (1998)
Modified chlorophyll absorption in reflectance	$MCARI = [(R700 - R670) - 0.2 \times (R780 - R550)] \times (R700/R670)$	Daughtry et al. (2000)
Modified chlorophyll absorption in reflectance	$MCARI1 = 1.2 \times [2.5 \times (R800 - R670) - 1.3 \times (R880 - R550)]$	Haboudane et al. (2004)
Modified chlorophyll absorption in reflectance	$MCARI2 = \frac{1.2 \times [2.5 \times (R800 - R670) - 1.2 \times (R880 - R550)]}{\sqrt{(2 \times R800 + 1)^2 - 6 \times (R880 - R550) - 12}}$	Haboudane et al. (2004)
Improved SAVI (soil-adjusted VI) with self-adjustment factor L	$MSAVI = \frac{1}{2} \times \left(2 + \frac{R800}{R710} + \sqrt{\left(2 + \frac{R800}{R710} + 1 \right)^2 - 8 \times \left(\frac{R800}{R710} - R670 \right)} \right)$	Qi et al. (1994)
Modified simple ratio	$MSR = \frac{(R800/R670) - 1}{\sqrt{(R800/R670) + 1}}$	Chen (1996)
Modified triangular VI	$MTI\% = 1.2 \times [1.2 \times (R800 - R550) - 2.5 \times (R670 - R550)]$	Rodríguez-Pérez et al. (2009)
Normalized difference vegetation index	$NDVI = \frac{R81 - R67}{R81 + R67}$	Rouse et al. (1974)
Optimized soil-adjusted vegetation index	$OSAVI = (1 + 0.16) \times (R800 - R670) / (R800 - R670 + 0.16)$	Rondeaux et al. (1996)
Simple ratio index	$SR1 = \frac{R81}{R52}$	Jordan (1969)
Photochemical reflectance index	$PRI = \frac{R710 - R530}{R710 + R530}$	Fuentes et al. (2001); Gamon and Surfus (1999)
Renormalized difference VI	$RDVI = \frac{R81 - R67}{R800 - R670}$	Rejc and Brco (1995)
Transformed chlorophyll absorption in reflectance	$TCARI = 3 \times [(R700 - R670) - 0.2 \times (R700 - R550)] \times (R700/R670)$	Haboudane et al. (2002)
TCARI/OSAVI	$TCARI/OSAVI = \frac{3 \times [(R700 - R670) - 0.2 \times (R700 - R550)] \times (R700/R670)}{1 + 0.16 \times (R800 - R670) / (R800 - R670 + 0.16)}$	Haboudane et al. (2002)

Source: Javier et al. (2012)

Thank you